CALIFORNIA DIVISION OF MINES AND GEOLOGY
FAULT EVALUATION REPORT FER-204

DEATH VALLEY FAULT ZONE
INYO AND SAN BERNARDINO COUNTIES, CALIFORNIA

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INTRODUCTION

The Death Valley fault zone is a major right-lateral oblique-slip fault of the western Basin and Range geologic province. It is a southward continuation of the Northern Death Valley-Furnace Creek fault zone evaluated by Bryant (1988), who recognized a Holocene-active right-lateral fault zone. In central Death Valley, between Furnace Creek and Shoreline Butte, the Death Valley fault zone has a more northerly trend than to either the north or south (Figure 1). This segment forms a right step in the fault zone and a "pull apart basin" (Burchfiel and Stewart, 1966). In southern Death Valley the movement is primarily strike-slip and topography is more subdued to the intersection of the Garlock fault in the northern Avawatz Mountains.

Right-lateral displacement across the fault zone has occurred from Tertiary through Holocene time and can be measured in kilometers (Wright and Troxel, 1967) or tens of kilometers (Stewart, 1967).

The Death Valley fault zone shows abundant evidence for Holocene activity and lies within the current Basin and Range study region. It is evaluated here for possible zoning under the Alquist-Priolo Special Studies Zones Act (Hart, 1988). Faults on the Furnace Creek, Devils Golf Course, Hanaupah Canyon, Badwater, Dantes View, Mormon Point, Gold Valley, Anvil Springs Canyon East, Shoreline Butte, Confidence Hills West, Confidence Hills East, East of Owl Lake and Old Ibex Pass 7.5-minute quadrangles are evaluated here (Figure 1). Many additional faults have been mapped on the west side of Death Valley (Hunt and Mabey, 1966; Brogan, 1979). These faults have been evaluated where they appear to be particularly active or occur on the same 7.5-minute quadrangle as the main trace. Many additional faults have not been evaluated in detail.

SUMMARY OF AVAILABLE DATA

The Death Valley fault zone is one of the principal fault zones of the southwestern Basin and Range geologic province.

Oblique extensional tectonics have resulted in both strike-slip and normal faults bounding mountain blocks.

The main trace of the Southern Death Valley fault zone follows the western front of the Black Mountains from Furnace Creek to Shoreline Butte (Fig. 1, quadrangles A-I.). West-dipping normal faults separate the playa and alluvial fan surfaces of the valley from the mountains which rise 5 to 6 thousand feet above. The main paved road through southern Death Valley follows the base of the Black Mountains and crosses over strands of the southern Death Valley fault zone several times. Tourist facilities at Furnace Creek are also very close to traces of the Southern Death Valley fault zone. South of Shoreline Butte the fault runs through the Confidence Hills, the "Noble Hills" (Brady, 1982) and adjoining basins to the Garlock fault. Extensions south of the Garlock fault have been postulated (Hamilton and Myers, 1966; Stewart and Poole, 1975; Brady, 1986a), but no Holocene movement has been proposed south of the Garlock fault.

Rocks units offset by the faults include Precambrian and Paleozoic metamorphic and sedimentary rocks, Tertiary sedimentary and volcanic rocks and Quaternary alluvium and lacustrine deposits (Hunt and Mabey, 1966; Drewes 1963; Wright and Troxel, 1984; Butler, 1984; Brady, 1986a; Streitz and Stinson, 1974; Hsu and Wagner, in progress).

Furnace Creek to Shoreline Butte

The main trace of the Death Valley fault zone has been mapped along the base of the Black Mountains by Hunt and Mabey (1966), Drewes (1967) and Brogan (1979). This area includes the famous "turtleback" surfaces (Curry, 1938), which are interpreted by Wright and others (1974) to be the exhumed surfaces of extensional faults. Hunt and Mabey show the major faults on the Furnace Creek and Bennetts Well quadrangles (Figure 2a, 2b) at a scale of 1:96,000. The small scale of the map requires a somewhat generalized depiction of faults, but Hunt and Mabey show faults offsetting Recent (=Holocene) alluvium (their Qf_4 unit) and placing Qf_4 against bedrock. They date the most recent scarps, from Furnace Creek south to Artists Drive, at about 2000 years old, based on archeological evidence.

Mapping by Drewes (1963) on the Bennetts Well and Funeral Peak quadrangles (Figure 2b) generally agrees with that of Hunt and Mabey (1966), but is plotted at somewhat larger scale (1:62,500) and shows somewhat more detail. Drewes does not distinguish between Pleistocene and Holocene units but faults are shown cutting his Qg unit, equivalent of Qf_2, Qf_3 (Pleistocene) and Qf_4 (Holocene) of Hunt and Mabey.

Brogan (1979) mapped late Quaternary geomorphic features along the Northern Death Valley-Furnace Creek fault zone and the Death Valley fault zone from Fish Lake Valley in Nevada to Shoreline Butte in southern Death Valley. Mapping by Brogan generally agrees with mapping by Hunt and Mabey and mapping by Drewes in central Death Valley (Figure 2a and 2b). Brogan shows more detail, particularly more minor scarps away from the mountain front. Brogan mapped scarps (generally west-facing) along the front of the Black Mountains and measured heights and slopes of scarps in the field. These are plotted on Figure 2a, 2b and 2c and with selected annotations. Scarps 1m to 5m high are common in alluvial material of latest Pleistocene or Holocene age. Slopes of the scarps range from approximately 30° to 90°.

The most recent displacements along the southern Death Valley fault zone have apparently occurred between Furnace Creek and Artists Drive (Figure 2a). Near Golden Canyon, Brogan (1979) mapped scarps, which he estimates to be 200 to 2000 years old, in unvarnished alluvial material . Scarps along Artists Drive displace materials of similar age, but do not appear to be as fresh. The scarps near Golden Canyon were estimated to be at least 2000 years old by Hunt and Mabey (1966). Indian storage pits dug into the scarp are about 2000 years old based on archeological evidence.

South of Artists Drive, Brogan (1979) mapped faults in Holocene deposits (Figure 2b, 2c), along the front of the Black Mountains. West facing scarps 1.2 to 1.8m high are common and have slopes of 30° - 35°. Brogan recognized normal offsets on most faults south of Furnace Creek and also recognized a right-lateral component locally.

Total offset on the Death Valley fault zone is unknown. Total normal offset may be approximated by the relief of the Black Mountains. The mountains rise up to 5,000 feet above the valley floor while Tertiary and Quaternary sediments fill the valley to a depth of 10,000 feet (Hunt and Mabey, 1966). A right-lateral component of movement, shown by en echelon faults and offset ridges and drainages has been recognized by Curry (1938), Drewes (1963), Hunt and Mabey (1966), Hill and Troxel (1966), Wright and Troxel (1984), and Brogan (1979). Troxel observed slickensides (striae) on the west flank of the turtleback surfaces and on many of the frontal faults on the west side of the Black Mountains which plunge 10° to 15° to the northwest (Troxel and Wright, 1987). The total strike-slip movements across the Southern Death Valley fault zone has been estimated, based on trends on Precambrian strata at up to 80 km (Stewart, 1967) or no more than 8 km (Wright and Troxell, 1967). Butler (1984) estimated 35 km of right-lateral offset based on sources of clasts in Tertiary and Quaternary fan deposits.

Quaternary vertical slip-rates for the normal faults at the base of the Black Mountains were calculated by Hooke (1972). Vertical movement of 7 mm/yr is based on calculated tilting rates of the Panamint Mountains block. These tilting rates are based on correlations of shorelines which are assumed to have formed during a high stand of Lake Manly 10,500 years ago. Uncertainties in these calculations include the correlation of a critical and very poorly preserved set of shorelines on the west side of Death Valley and the dating of the high stand of Lake Manly. Hooke correlates the high stand with a high stand of Lake Searles at the end of the Tioga glaciation. The poor preservation of these shorelines suggests that they may be older than 10,500 years. Butler (1984) argues that all shorelines above sea level must be older than 75,000 years based on fluvial features at the southern end of Death Valley. If the shorelines used by Hooke are over 75,000 years old rather 10,500, then his 7 mm/yr vertical slip rate is too high by at least a factor of 7.

A more accurate estimate of the vertical slip-rate may be made using the shoreline of the most recent lake. This lake occupied the floor of Death Valley more than 2000 years ago, based on archeological evidence (Hunt and Mabey, 1966). Shorelines of this lake are at an elevation of -240 feet on the west side of the valley and approximately -260 feet on the east side. If this difference in elevation has occurred due to faulting on the east side of the valley, a maximum vertical slip rate of 6m in 2000 years or 3mm/year can be calculated. Because the shorelines may be considerably older than 2000 years, this slip rate can be regarded as a maximum.

<u>South of Shoreline Butte</u>

At Shoreline Butte, on the north half of the Confidence Hills 15' quadrangle, the Death Valley fault zone changes character. It changes trend from north to N30°W and becomes a strike-slip fault with only a minor vertical component. The Death Valley fault zone on the Confidence Hills 15' quadrangle has been mapped by Wright and Troxel (1984) and Butler (1984). A small portion of the central Confidence Hills is not covered by a published geologic map, but a copy of Troxel's field map is included in Troxel and Butler (1986).

South of Shoreline Butte the Death Valley fault zone offsets Plio-Pleistocene lacustrine sediments in the Confidence Hills and older alluvium shed from the Owlshead Mountains. Wright and Troxel (1984) and Butler (1984) map offsets of older alluvial units but no offsets of Holocene units have been mapped in the Confidence Hills quadrangle.

South of the Confidence Hills, Butler, (1984); Brady, (1986) and Troxel (unpublished) have mapped faults along the Amargosa River and through the "Noble Hills" (Brady, 1986a) (Fig. 2c,d).

Right-lateral offset of 20 km (Brady, 1986a) to 35 km (Butler, 1984) has been estimated based on offset sedimentary facies in Quaternary alluvial deposits. Several strands of the Death Valley fault zone through the "Noble Hills" are progressively younger from southwest to northeast (Troxel, 1970). The youngest of these are reported to cut Holocene sediments (Troxel, 1970).

The area where the Death Valley fault zone intersects the Garlock fault has been mapped by Brady (1986a). Brady has calculated 20 km of Pliocene and Quaternary right-lateral displacement along the Death Valley fault zone (Brady, 1984). Strands of the fault along the northeastern margin of the "Noble Hills" offset Holocene alluvium (Brady's Qf_3 and Qf_4 units). These strands are the same as mapped by Troxel (1970). South of the central "Noble Hills" faults are not shown offsetting units younger than Qf_2 (Pleistocene to Holocene) (figure 2d).

West Side of Death Valley

Many normal faults have been mapped on the west side of Death Valley by Hunt and Mabey (1966) and Brogan (1979). Hunt and Mabey mapped several short, straight, normal faults offsetting their Qg_2 unit (upper Pleistocene). One of these faults along the Hanaupah escarpment offsets Qg_3, the youngest upper Pleistocene unit (Figure 2b). Brogan mapped many additional faults on the Furnace Creek, Bennetts Well and Wingate Wash 15'quadrangles (Figures 2a,b,c). These faults are also mapped on older dissected portions of the alluvial fans. Brogan did not annotate his map of faults on the west side of Death Valley, as he did on the east side. It is only possible to classify these faults as late Quaternary based on Brogan's work.

INTERPRETATION OF AERIAL PHOTOGRAPHS AND FIELD CHECKING

Faults of the Death Valley fault zone were interpreted using aerial photographs taken by the University of Nevada-Reno (flight DVF: low sun angle, scale approximately 1:12,000); the U.S. Geological Survey (Flights VDFT and VEYG, scale approximately 1:24,000) and the U.S. Department of Agriculture (Flight AXL, scale approximately 1:20,000). Faults interpreted to be sufficiently active and well defined for zoning under the Alquist-Priolo Special Studies Zones Act (Hart, 1988) were plotted on 7.5-minute quadrangles (Figures 3a-g). The 7.5-minute Dantes View quadrangle map is not yet available, faults that cross the southwest corner of the Dantes View quadrangle are plotted on the margin of the Badwater quadrangle (Figure 3c). The more detailed topography on the 7.5-minute base maps allows more accurate and detailed plotting of fault features. This difference in base map probably accounts for most of the minor differences in location of faults mapped by Brogan (1979) and faults mapped for this study.

This writer and E.W. Hart spent approximately 5 days in southern Death Valley in January and March 1989 field checking critical fault features. Features field checked included those that appeared to be most likely to yield a sense or magnitude of the most recent movement and those of doubtful origin or age. Field data and aerial photo interpretations are summarized on figures 3a to 3g.

Furnace Creek to Shoreline Butte

From Furnace Creek to Shoreline Butte in central Death Valley the Death Valley fault zone is a right-oblique fault with the west side downdropped. At the north edge of the Furnace Creek 7.5-minute quadrangle two en echelon anticlines in Pliocene and Pleistocene deposits may reflect right-lateral movement. A side-hill bench at locality 1 (Figure 3a) represents the northernmost well-defined surface fault. To the south, the young alluvium of the Furnace Creek alluvial fan generally obscures evidence for faulting. Northeast of the Death Valley National Monument Visitor Center at locality 2 (Figure 3a) the fault is well defined by a side-hill trough in older alluvium. Recency of movement is indicated by closed depressions, right-lateral deflections of minor drainages and a scarp in Holocene alluvium in one of the major drainages. Southeast of locality 2 the fault is defined by truncated ridges of older alluvium.

South of Furnace Creek (the apex of the Furnace Creek alluvial fan), west facing scarps in young alluvium follow the base of the Black Mountains. These features are well defined, except where they have been obscured by the road, and are coincident with the faults mapped by Hunt and Mabey (1966) and Brogan (1979). The scarp south of Breakfast Canyon (locality 3, figure 3a) was field checked. The young age of this fault is indicated by weakly developed soil and desert varnish on the offset fan surface and the steep slope of the scarp. At one location along this scarp two crests were observed, the upper more rounded than the lower. The upper, rounded scarp is less than 1m high and has formed in Holocene time. The lower, sharp scarp approximately 1½m high may have formed during a later earthquake. Right-lateral offset may be indicated by numerous small gullys that cross the scarp. These gullys trend about 30° clockwise to the scarp. This odd arrangement of gullys, which does not seem to be related to the local drainage pattern, is consistent with the orientation of tension fractures (riedel shears) along a right-lateral fault.

Near Desolation Canyon the fault zone diverges from the valley floor and separates a block of volcanic bedrock from the Black Mountains. The fault is well defined by scarps in bedrock and linear drainages along the northern part of this segment. Minor drainages appear to be right-laterally deflected at locality 4 (figure 3a). South of locality 4, the fault zone is defined by linear drainages and saddles to the broad trough followed by Artists Drive (Fig. 3b). Along one segment, several minor drainages are consistently offset 3 to 4m in a right-lateral sense (Figure 2b).

From Artists Drive to Natural Bridge canyon, the Death Valley fault zone is poorly defined and discontinuous (Figure 3b). Evidence for recent movement was not found along the traces of the fault (mostly mapped as concealed) of Hunt and Mabey (1966) (Figure 2a). Faults mapped by Brogan (1979) are discontinuous and were verified at locality 5 (Figure 3b) as several low, degraded scarps in older alluvium.

At Natural Bridge canyon, the main trace of the Death Valley fault zone returns to the floor of Death Valley. From this point south to Shoreline Butte, the fault zone bounds the east side of the valley and separates the valley from the Black Mountains. Faults along this portion of the zone have been mapped by Drewes (1963), Hunt and Mabey (1966), Brogan (1979), and Wright and Troxel (1984). Faults mapped by these investigators are generally in good agreement along this portion of the fault and were generally verified by this writer.

The general north-northwesterly trend of the fault zone is interrupted on the Badwater, Gold Valley and Mormon Point quadrangles (Figures 3c,d) by the surfaces of the Badwater and Mormon Point turtlebacks. These antiformal surfaces of extensional faults (Wright and others 1974) deflect the margin of the valley and are reflected by deformation of the salt pan along the trend of the axes of the turtlebacks (Hunt and Mabey, 1966). Holocene faults closely follow the southwestern sides of the turtlebacks and northeasterly trending faults are distributed in the re-entrants north of both Mormon Point and, to a lesser extent, at Badwater. Scarps at the head of the Badwater alluvial fan (locality 6, figure 3c) were field checked and were the highest Holocene scarps observed. These scarps are up to 10m high and have a 3 to 4m high free face. They offset a fan surface that is only weakly varnished and soil with little or no caliche.

Numerous graben cut the toe of the Badwater alluvial fan (locality 7, figure 3c). These are up to 3m deep, sharply bounded and somewhat sinuous. Their orientation is consistent with northwestward extension, however, they are due to lateral spreading and liquefaction of sand layers within the alluvial material. Numerous other fissures and small scarps mapped by Brogan (1979) follow the base of the alluvial fans south of Badwater (locality 8, figure 2b). These have a variety of orientations and probably are due to liquefaction.

Right-lateral offset along the fault on the southwest side of the Copper Canyon and Mormon Point turtlebacks (figure 3d) seems likely based on their linearity. Right-lateral offset of distributary channels on the south side of the Copper Canyon alluvial fan (locality 9, figure 3d) also indicates a right-lateral component. The right-laterally deflected drainage at locality 10 (figure 3d) does not indicate right-lateral offset but probably occurred by the drainage being blocked by a backfacing scarp and deflected down fan.

On the Shoreline Butte quadrangle the Death Valley fault zone begins a series of large, roughly en echelon steps away from the front of the Black Mountains (figure 3e). These and the right-laterally deflected drainage at locality 11 (figure 3e) indicate a right-lateral component of motion. Scarps in young alluvium, older alluvium and Pleistocene basalt define this portion of the fault zone. Roughly en echelon fresh scarps in young alluvium were noted by Brogan (1979) at locality 12 (figure 3e) and were verified by this writer.

South of Shoreline Butte

At Shoreline Butte in southern Death Valley the southern Death Valley fault zone forms scarps and a sidehill trough in Pleistocene basalt. These features (locality 13, figure 3e) are considerably sharper and "fresher" than adjacent Pleistocene shorelines and may truncate those shorelines. This fault was mapped by Noble (1941) (reproduced in Wright and Troxel, 1984), but was not shown as a fault by Wright and Troxel (1984). It was reinterpreted to be a bed of volcanic ash in the basalts of Shoreline Butte (B.W. Troxel, personal communication, 1988). This feature was field checked and is interpreted to be a fault based on the following evidence: The linearity of the drainage and side-hill bench, closed or nearly closed depressions on the side-hill bench, shears in bedrock at the north end of the linear drainage, the right-laterally deflected drainage at the same location and the contrast between the unvarnished and irregularly varnished boulders along the fault with the well-varnished boulders on the adjoining slopes. The irregularly varnished boulders along the fault may be fault-stirred rubble. This strand of the fault continues southward and is defined by scarps in late Pleistocene alluvium. Other strands of the southern Death Valley fault zone mapped by Wright and Troxel (1984) at Shoreline Butte and to the north at Cinder Hill (figure 2c) do not show evidence of Holocene movement.

South of Shoreline Butte the fault trends approximately N40°W along the axis and southeast flank of the Confidence Hills (figures 3e and 3f). Along the majority of this trace, older alluvium is faulted against Plio-Pleistocene lacustrine deposits. Recency of faulting is expressed by aligned drainages and saddles, right-laterally deflected drainages, sidehill benches, and recent alluvium ponded behind the uplifting Confidence Hills (figure 3f). Northwest of locality 14, (Figure 3f) the fault is exposed as sheared, gypsum-cemented mudstone along a linear drainage. This linear drainage is right-laterally offset 360m by the fault. Each of the two minor drainages that enter the linear drainage from the southwest is right-laterally deflected as it approaches the fault zone.

At locality 14, (figure 3f) a minor drainage is offset approximately 30m right-laterally and the fault is marked by a series of aligned sinkholes on the side-hill bench. To the southeast, the fault is expressed as a sharp side-hill bench in soft lacustrine mudstone. Each minor drainage to the southeast is sharply deflected right-laterally as it crosses the fault. The sharpest deflection is typically about 3 meters.

Further to the southeast lacustrine mudstones are in fault contact with the alluvial sand and gravel which unconformably overlie them. Clasts in the alluvium are rotated to vertical in the fault zone.

At the southern end of the Confidence Hills (locality 15, figure 3f) is a 1.8m-high scarp in older gravels with a maximum slope angle of 28°. The steepness of the slope may indicate Holocene movement. South of the Confidence Hills evidence for recent faulting is relatively obscure in a basin floored with recent alluvium. Faults mapped by Butler (1984) offset bedrock and older alluvium on the west side of the basin but do not have good evidence for Holocene movement. Faults extending into this basin from the southeast (Butler, 1984) are well defined and show good evidence for Holocene movement including sharply deflected minor drainages at locality 16 (Figure 3g).

At locality 16 (figure 3g) the fault is defined by a linear ridge 20 to 50 cm high and a sharp tonal contrast visible both on aerial photos and on the ground. Each of the minor incised drainages in lacustrine mudstone is right-laterally offset. The sharpest right-lateral offset is commonly about 3m. One drainage clearly shows two 1.2m, right-lateral steps in its north wall, one very sharp at the fault and another, more rounded, which appears to have migrated downstream by erosion. These may indicate a characteristic offset of about 1.2m per event for this fault strand.

A parallel strand of the fault to the east also deflects drainages right-laterally and also offsets the ground surface down to the east. The sharpest right-lateral offset of a minor gully is approximately 3m and the greatest deflection of an entrenched drainage is 27m (at locality 17, figure 3g). A minor branch fault exposed in the wall of the entrenched drainage, downstream from the major fault, has grooves on its surface which plunge to the northwest at 10 to 15°. This eastern fault trace apparently dies out or is covered by younger alluvium to the southeast. Further to the southeast, possible continuations at locality 18 (figure 3g) are defined by truncated bedding, broad breaks in slope and aligned dunes. No clear evidence for Holocene offset was observed at or near locality 18, although Pleistocene beds are clearly truncated.

The main trace of the southern Death Valley fault zone can be traced to the southeast to locality 19 (figure 3g) where it offsets a fold in Quaternary lacustrine deposits (Troxel and Butler, 1986). No clear evidence for Holocene offset was observed along this fold although this very soft mudstone with no entrenched drainage channels may not preserve fault related geomorphic features for a significant amount of time.

Further to the southeast evidence for Quaternary faulting can be seen along the northeastern side of the "Noble Hills" (figure 3g). Degraded east facing scarps in older alluvium bound the hills on the northwest. Slight scarps and tonal lineaments in young alluvium at locality 20 (figure 3g) indicate limited Holocene movement along this strand of the fault. Two right-laterally deflected drainages on another strand of the Death Valley fault zone higher in the hills may indicate some late Quaternary activity on that strand.

To the south, geomorphic evidence for Holocene faulting was not observed on the southern Death Valley fault zone from the central "Noble Hills" to the Garlock fault in the northern Avawatz Mountains (figure 2d). This portion of the fault zone may have had 20 km of right-lateral movement since the Pliocene (Brady, 1986a), but it lacks evidence of Holocene movement.

<u>West Side of Death Valley</u>

The numerous, discontinuous, normal faults mapped by Brogan (1979) on the west side of Death Valley were verified on aerial photographs as faults, but they generally are degraded scarps on old alluvial fans. Those scarps which appear to be broad, rounded scarps in old alluvium (Qg2 of Hunt and Mabey, 1966) were briefly reviewed on 1/12,000 scale aerial photos. Only those scarps which appeared sharply defined or to offset younger alluvium were examined in detail.

Faults which offset alluvium of probable Holocene age extend on a northwesterly trend across the northeastern portion of the Anvil Springs Canyon East 7.5-minute quadrangle and onto the Mormon Point quadrangle (Figures 3d and 3e). Left-stepping en echelon scarps and graben may indicate a right-lateral component of movement. These faults are expressed as east facing scarps in late Pleistocene alluvium (probably equivalent to Qg3 of Hunt and Mabey, 1966) and as en echelon graben in equivalent and younger alluvium (figure 3e).

This younger alluvium is probably equivalent to Qg4 (Holocene) of Hunt and Mabey (1966). It is probably not completely Holocene however, some areas are elevated above present channels and have weakly developed desert varnish. These are probably of latest Pleistocene to Holocene age. The most recent channels and some adjoining areas contain alluvium that has no desert pavement or varnish, this material is almost certainly of Holocene age. Some scarps are developed only in late Pleistocene alluvium, others offset Late Pleistocene and latest Pleistocene to Holocene alluvium. Locally, scarps are developed in alluvium which appears to be only slightly older than the modern channels.

Relatively young scarps also are expressed to the northwest on the Mormon Point quadrangle (figure 3d) and the Badwater and Hanaupah Canyon quadrangles (figure 3c). With the exception of the well-defined scarp on the Hanaupah Canyon quadrangle, these features are minor and discontinuous. The well defined scarp on the Hanaupah Canyon quadrangle was described by Hunt and Mabey because it clearly offsets their Qg2 unit more than the younger Qg3, demonstrating recurring movement. The sharpness of the scarp, and the relatively slight incision by drainages that cross the scarp observed on aerial photographs indicate a probable late Holocene age for the most recent movement on this fault.

It is possible that there are other Holocene faults on the west side of Death Valley as not all faults were carefully checked and some areas lacked air photo coverage.

SEISMICITY

Very few well-located (A or B quality) earthquakes have occurred in the southern Death Valley region in the period 1960-1985 (Caltech, 1985). Numerous, poorly located epicenters occur west of the southern Death Valley fault zone south of 36° latitude. No events in the Caltech catalog can be definitely related to the southern Death Valley fault zone, partly due to a generally low level of seismicity in the area and partly due to the sparse instrumentation and poorly located epicenters.

CONCLUSIONS

The Death Valley fault zone is a major right-lateral oblique slip fault of the western Basin and Range. It is part of a larger system which extends about 350km from Fish Lake Valley in Nevada to the Garlock fault. The northern part of this system, the Northern Death Valley-Furnace Creek fault zone, is a Holocene-active right-lateral fault (Bryant, 1988). The southern part of the system, the Death Valley fault zone is an oblique slip fault from Furnace Creek to Shoreline Butte and right-lateral farther south.

The Death Valley fault zone exhibits abundant evidence for recurrent Holocene movement between Furnace Creek and Shoreline Butte. Right-oblique movement is indicated by numerous west-facing scarps and right-laterally deflected drainages of many locations along the east side of Death Valley.

South of Shoreline Butte, the Death Valley fault zone is a right-lateral strike-slip fault with little or no normal component. The fault is well defined through the Confidence Hills where it largely coincides with the trace previously mapped by Wright and Troxel (1984); Troxel (in Troxel and Butler, 1986) and Butler (1984). Continuing movement on this trace is indicated by greater deformation of Pleistocene lacustrine deposits and lesser deformation of the overlying fanglomerate. Holocene offset is indicated by right-lateral offset of minor drainages and sidehill benches in soft mudstone.

Many minor drainages were right-laterally deflected in the Confidence Hills and to the south. The common 3 to 4 meter deflection may indicate a characteristic offset for this segment of the fault zone. Alternatively, these deflections may represent more than one earthquake. Two offsets of about 1.2m each are indicated at locality 16 (Figure 3g) and this may represent the typical offset. The fault is not well defined across the basin south of the Confidence Hills but two traces are well defined on the East of Owl Lake quadrangle (figure 3g). Evidence for Holocene offset diminishes to the south. The faults in the "Noble Hills" may locally offset Holocene alluvium (Figure 3g) but scarps are lower and more degraded than those to the north. Evidence for Holocene movement was not observed on faults in the southern "Noble Hills".

Faults on the west side of Death Valley show evidence for both right-lateral and normal offset. Sufficiently active and well defined faults closely follow the West Side Road on the Anvil Springs Canyon East, Mormon Point, Badwater and Hanaupah Canyon quadrangles. Many additional faults to the west have been mapped by Brogan (1979). These appear to be mostly pre-Holocene features, but they were incompletely evaluated.

RECOMMENDATIONS

Most of the main traces of the Death Valley fault zone evaluated by this study meet the criteria of Holocene active and well-defined (Hart, 1988,). Only a few of the numerous minor faults on the west side of Death Valley meet these criteria, however. The minor faults on the Anvil Springs Canyon East quadrangle are in very remote area and zoning is not warranted.

Zone for special studies well-defined traces of the Southern Death Valley faut zone as depicted in yellow highlighting on Figures 3a,b,c,d,e,f, and g. Principal references cited should be Brogan (1979) and Wills (this report) on the Furnace Creek, Devils Golf Course, Badwater, Hanaupah Canyon, and Mormon Point quadrangles; Brogan (1979) Wright and Troxel (1984) and Wills (this report) on the Shoreline Butte quadrangle, Butler (1984) and Wills (this report) on the Confidence Hills West, Confidence Hills East and East of Owl Lake quadrangles and Brady (1986a) and Wills (this report) on the Old Ibex Pass quadrangle.

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Reviewed; recommendations approved. Earl W. Hart 3/22/89

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REFERENCES

Brady, R.H. III, 1982, Geology at the intersection of the Garlock and Death Valley fault zones. Northeastern Avawatz Mountains, California, a field guide, p. 53-60 in Cooper, J.D., B.W. Troxel and L.A. Wright, editors, Geology of selected areas in the San Bernardino Mountains, western Mojave Desert and southern Great Basin, California: Geological Society of America, Cordilleran Section Volume and guidebook.

Brady, R.H. III, 1984, Neogene stratigraphy of the Avawatz Mountains between the Garlock and Death Valley fault zones, southern Death Valley, California: Implications as to late Cenozoic tectonism, Sedimentary Geology, v. 38, p. 127-157.

Brady, R.H. III, 1986a, Cenozoic geology of the northern Avawatz Mountains in relation to the intersection of the Garlock and Death Valley fault zones, San Bernardino County, California, unpublished Ph.D dissertation, University of California-Davis, 296p.

Brady, R.H. III, 1986b, Stratigraphy and tectonics of the northern Avawatz Mountains at the intersection of the Garlock and Death Valley fault zones, San Bernardino County, California - a field guide. in Troxel, B.W., editor, Quaternary tectonics of southern Death Valley: Friends of the Pleistocene, Pacific Cell Field Guide, October 31-November 2, 1986, p. 1-13.

Bryant, W.A., 1988, Northern Death Valley-Furnace Creek fault zone: California Division of Mines and Geology Fault Evaluation Report FER-193, 20 p. (unpublished report).

Brogan, G.E., 1979, Late Quaternary faulting along the Death Valley-Furnace Creek fault system, California and Nevada, U.S. Geological Survey, Earthquake Hazards Reduction Program Contract #14-08-0001-17801, 128 p., 10 plates (unpublished report).

Burchfiel, B.C., and Stewart, J.H., 1966, "Pull-apart" origin of the central part of Death Valley, California: Geological Society of America Bulletin, v. 77, p. 439-442.

Butler, P.R., 1982, Quaternary history of selected sites in the lower Amargosa River basin, southern Death Valley, California in Cooper, J.D., B.W. Troxel, and L.A. Wright, editors, Geology of selected areas in the San Bernardino Mountains, western Mojave Desert and southern Great Basin, California: Geological Society of America, Cordilleran Section, volume and guidebook, p. 49-52 .

Butler, P.R., 1984, Geology, structural history and fluvial geomorphology of the southern Death Valley fault zone, Inyo and San Bernardino Counties, California, unpublished Ph.D dissertation, University of California-Davis, 122 p.

California Institute of Technology, 1985, Magnetic tape catalog, southern California earthquakes for the period 1932 to 1984: Seismological Laboratory, California Institute of Technology (unpublished).

Curry, H.D., 1938, "Turtleback" fault surfaces in Death Valley, California (abstract): Geological Society of America Bulletin, v. 49, p. 1875.

Drewes, H., 1963, Geology of the Funeral Peak quadrangle, California, on the east flank of Death Valley: U.S. Geological Survey Professional Paper 413, 75p.

Hamilton, W.B., and Myers, W.B., 1966, Cenozoic tectonics of the Western United States: Reviews of Geophysics, v.4, p. 509-549.

Hart, E.W., 1988, Fault-rupture hazard zones in California: California Division of Mines and Geology Special Publication 42, 24p.

Hill, M.L., and Troxel, B.W., 1966, Tectonics of Death Valley region, California: Geological Society of America Bulletin, v. 77, p. 435-438.

Hooke, R., Leb, 1972, Geomorphic evidence for Late-Wisconsin and Holocene tectonic deformation, Death Valley, California: Geological Society of America Bulletin, v. 83, p. 2073-2098.

Hsu, E.Y., and Wagner, D.L., (in progress) Geologic map of the Trona-Kingman quadrangle: California Division of Mines and Geology Regional Geologic Map Series, scale 1:250,000.

Hunt, C.B., and Mabey D.R., 1966, Stratigraphy and Structure, Death Valley, California: U.S. Geological Survey Professional Paper 494-A, 162 p.

Noble L.F., 1941, Structural features of the Virgin Spring area, Death Valley, California: Geological Society of America Bulletin, v. 52, p. 942-1000.

Noble, L.F., and Wright, L.A., 1954, Geology of the central and southern Death Valley region, California, in Jahns, R.H., editor, Geology of southern California: California Division of Mines and Geology Bulletin 170, Chapter II, p. 143-160.

Stewart, J.H., 1967, Possible large right-lateral displacement along fault and shear zones in the Death Valley-Las Vegas area, California and Nevada: Geological Society of America Bulletin, v. 78, p. 131-142.

Stewart, J.H., and Poole, F.G., 1975, Extension of the Cordilleran miogeosynclinal belt to the San Andreas fault, southern California: Geological Society of America Bulletin, v. 86, p. 205-212.

Streitz, R.S., and Stinson, M.C., 1974, Death Valley sheet: California Division of Mines and Geology Geologic Map of California, scale 1:250,000.

Troxel, B.W., 1970, Anatomy of a fault zone, southern Death Valley, California: Geological Society of America, Cordilleran Section, Abstracts with Programs for 1970, p. 154.

Troxel, B.W., and Butler, P.R., 1986, Multiple Quaternary deformation, central part of the Confidence Hills, Death Valley, California: an example of folding along a strike-slip fault zone, in Troxel, B.W., editor, Quaternary tectonics of southern Death Valley, California: Friends of the Pleistocene, Pacific Cell, Field Guide, p. 25-28.

Wright, L.W., Otton, J.K., and Troxel, B.W., 1974, Turtleback surfaces of Death Valley viewed as phenomena of extensional tectonics in Troxel, B.W., editor Guidebook: Death Valley Region, California and Nevada: California Division of Mines and Geology, Special Report 106, p. 79-80 .

Wright, L.A., and Troxel, B.W., 1967, Limitations on right-lateral, strike-slip displacement, Death Valley and Furnace Creek fault zones, California: Geological Society of America Bulletin, v. 78, p. 933-950.

Wright, L.A., and Troxel, B.W., 1984, Geology of the north ½ Confidence Hills quadrangle, Inyo County, California: California Division of Mines and Geology Map Sheet 34.

University of Nevada-Reno, 1969 and 1970, Aerial Photographs DVF-20-8 - 128 to 210; DVF-24-6-112 to 125; DVF-25-7-130 to 146, black and white, vertical, scale approximately 1:12,000.

U.S. Department of Agriculture, 1953, Aerial Photographs AXL-33K-19 to 21, 12K-97 to 101 and 125 to 127, 13K-175 to 190, black and white, vertical, scale approximately 1:20,000.

U.S. Geological Survey, 1980, Aerial Photographs GS-VEYG-C 1-50 to 1-54, 1-122 to 1-126, 1-161 to 1-165, 2-19 to 2-22, 4-55 to 4-57, black and white, vertical, scale 1:24,000.

U.S. Geological Survey, 1982, Aerial Photographs GS-VFDT 3-7 to 3-10, 3-70 to 3-74, 3-105 to 3-108, 5-180 to 5-189, 7-193 to 7-210 14-110 to 14-125, black and white, vertical, scale 1:20,000.

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